METHOD FOR CALIBRATING A PROJECTOR WITH A CAMERA

FIELD OF THE INVENTION

Background of the Invention

Portable digital projectors are now common. These projectors, while connected to a PC or VCR, typically sit on a table and are aimed at a display surface to show a slide presentation or a video. Many of these projectors use transmission LCDs, and often only have a single main lens. The projectors can display images one at the time, or as a sequence of images.

Many of these projectors are designed so that level undistorted images are projected on the display surface when the projector is placed horizontally on a level support surface, so that the projector's optical axis is lined up perpendicular to the, typically, vertical projection surface. If any of the above assumptions is violated, then the resulting image on the projection surface may not be rectangular and will be, at best, a trapezoid, and at worst an arbitrary quadrilateral. This problem is called keystoning.

With prior art projectors, the only way to correct keystoning is to tediously adjust the physical position of the projector by moving it around, tilting and rotating it, until a near rectangular image is displayed. In some cases, it may be impossible to physically adjust the position of the projector. For example, the projector may need to be well above or below the display surface. Some prior art projectors correct the distorted image optically or by the user providing projector positional data. In order to correct the distorted image automatically, the projector needs to be calibrated. However, projectors have received little attention in the fields of computer vision or projective geometry.

Calibration processes for cameras are well know. Typically, the camera's optical system is expressed with a pinhole camera model. However, there are two main differences between a projector and a camera. First and most obvious, projectors, being output only devices, cannot view a calibration pattern as is done for cameras. It is easy to calibrate a projector given the correspondence between six or more 2D projector pixels and corresponding 3D points on a known target object, see O. Faugeras. "Three-Dimensional Computer Vision: A Geometric Viewpoint,"MIT Press, Cambridge, Mass., 1993. That technique requires a tedious manual process to select those projector pixels which illuminate the 3D points.

To automate this or any other semiautomatic method, an input device such as a camera must be used. The second main difference between a projector and a camera is that the traditional assumption about simplified camera models, that the principal point is close to the image center, is not valid for projectors. Most projectors use an off-axis projection. When they are set on a table or mounted on a ceiling, the image is projected through the upper or the lower half of the lens, respectively. Hence, the principal point is vertically shifted.

It is possible to attach two or more cameras to a projector, and use a projected calibration image and stereo calibration techniques. However, multiple camera increase cost, processing resources, and bandwidth. In addition, mounting multiple cameras on a projector would require extensive modifications to the design of existing projectors.

Therefore, there is a need for a simplified system and method for calibrating a digital projector.

SUMMARY OF THE INVENTION

The invention provides a method for calibrating a projector with a camera being a fixed physical relationship relative to each other. An output image is projected onto a display surface for a first and second pose of the projector and the camera relative to a display surface. For each pose, an input image is acquired.

For each pose, a projector perspective projection matrix and a camera perspective projection matrix is determined from each input image. For each pose, a transformation from the projector perspective projection matrix and the camera perspective projection matrix to Euclidean form is determined, and the projector intrinsic parameters from the transformations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for calibrating a projector with a single camera according to the invention;

FIG. **2** is a flow diagram of a method calibrating the projector with the single camera according to the invention; and

FIGS. **3***a*–*b* a diagrams of vertical offsets from a principle point.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Calibration System

As shown in FIG. **1**, our invention provides a method for calibrating a projector **100** that is in a fixed position with respect to a camera **110**. Preferably, the projector uses digital output mechanisms. The projector **100** is capable of displaying an output image **103** on a display surface **104**. Typically, the projector **100** is positioned on a table **120**, in a projection booth, or mounted on a ceiling. Therefore, the projector **100** is not always positioned perfectly perpendicularly to the display surface, and the output image **103** appears warped. This is typically called "keystoning".

Therefore, the camera **110** acquires an input image of the projected output image, and determines calibration parameters and correction parameters to the projector. These parameters can than be used to "unwarp" the output image **103** so that it appears correctly in a rectangular form **105**. The problem is that the projector is only an output device, and thus, has no means to determine how its position affects the warping.

Our method determines intrinsic parameters for both the projector **100** and the camera **110**, and their relative pose. Then, a post-calibration rendering process can utilize this information in conjunction with a gravity based tilt sensing **130**, which provides vertical coordinates, to unwarp the projected image **103**.

Calibration Method

As shown in FIG. **2**, first, we project **210** the calibration pattern **140** onto the display surface **104** for two different poses of the projector **100** and the camera **110** relative to the display surface. For each pose, we next acquire **220** an input image of the projected pattern. We obtain **230** the intrinsic parameters of the camera **110** using the multiple views of the calibration pattern in a process similar to the one described by Zhang, Z., "Flexible camera calibration by viewing a plane from unknown orientations," Proc. 7th Int. Conference on Computer Vision, pp. 666–673, 1999, and Sturm, P. and Maybank, S., "On plane-based camera calibration: A general algorithm, singularities, applications," Proc. of IEEE Conference on Computer Vision and Pattern Recognition, pp.432–437, Jun. 1999.